CIRCUIT CIRCUS

By Charles D. Rakes

Meter-Range Extender Circuits

This time around, we're starting the Circus off with a circuit that increases the sensitivity of an analog current meter. Usually the price of a meter is based primarily on its sensitivity, size, and overall accuracy. A 0–1-mA meter can often be purchased for considerably less than a comparable 50- or 100-mA microammeter, and is generally easier to find.

AMPLIFIED DC MICROAMMETER

The circuit in Fig. 1 turns a 0–1-mA milliammeter into a sensitive microammeter, while providing a choice of three current ranges. The first step increases the meter's sensitivity by a factor of 10 (0 to 100 microamps), the second step by a factor of 100 (0 to 10 microamps), and the third step increases the meter's sensitivity 1000 times (0 to 1 μA).

Even if you could locate an analog 0- to 1-μA meter, the cost would be prohibitive for most of us. But with a single IC, a few support components, and an inexpensive 0- to 1-mA meter, you can build your own 0- to 1-μA meter for a fraction of the cost of commercial microammeters. Magic? Not at all, just a small dose of good old electronic circuitry applied to an electro-mechanical device, turning it into a more useful tool.

In Fig. 1, a 741 op-amp is connected in a conventional inverting-amplifier circuit with the gain set by the resistor combinations of R1, R2, R3, and R4. Resistor R1 is connected to the input of the op-amp and serves as a current-sampling resistor. The 0–1-mA meter is connected between the op-amp's output, at pin 6, and through a calibration potentiometer, R11, to the wiper of a zero-adjust control, R10.

With no signal applied to the input of the circuit, the voltage at pin 6 of U1 is about half the supply voltage. The voltage at the center of R10 is also equal to half the supply voltage, allowing the meter to be zeroed for each current range. With S2 in position 1, the feedback resistor, R2, sets the op-amp's voltage gain to 10. With a current flow of 100 microamps through R1, the voltage across it normally would be 100 millivolts. (E = IR, or .0001 × 1000 = 0.1 volt) But due to the action of the op-amp's feedback current, the voltage will actually measure close to zero.

Now, if we make the resistor value that's connected to the op-amp's output (R11 + M1's internal resistance) equal in value to R1, the voltage developed across it should be ten times greater than the voltage across R1 with the op-amp gain of ×10. That produces a voltage of about 1 volt across the meter and R11. Divide 1 volt by 1k and you end up with a 1-mA current flow through the meter and R11, and the meter will read full scale. By changing the op-amp's

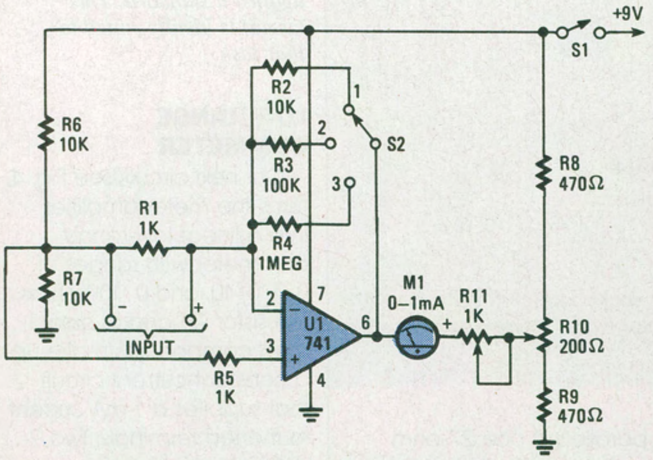

Fig. 1. The ammeter add-on circuit uses a 741 general-purpose low-power op-amp to boost micro-range current levels sufficiently to drive a 1-mA full-scale meter movement.

PARTS LIST FOR THE AMPLIFIED DC MICROAMMETER

RESISTORS

(All fixed resistors are ¼-watt, 5% units.)
R1, R5—1000-ohm
R2, R6, R7—10,000-ohm
R3—100,000-ohm
R4—1-megohm
R8, R9—470-ohm
R10—200-ohm potentiometer
R11—1000-ohm potentiometer

ADDITIONAL PARTS AND MATERIALS

U1—741 op-amp, integrated circuit
M1—0–1-mA meter
S1—SPST switch
S2—SP3T switch
Perfboard materials, enclosure, IC socket, test terminals, 9-volt battery, battery holder and connector, wire, solder, hardware, etc.

gain for each range, the output-voltage changes for a full-scale reading are about the same.

Because of the circuit's simplicity, the fixed resistors can be assembled on a 1 × 2 inch section of perfboard and connected to the meter, switches (S1 and S2), and control potentiometers (R10 and R11) through hook-up wire. The circuit can then be housed in an inexpensive plastic cabinet that's large enough to accommodate the perfboard and the off-board components.

To use the circuit, simply connect a 9-volt battery to the circuit and apply power. Place S2 in position 1 and adjust R10 for a zero meter reading. To calibrate the full-scale meter reading, take a new general-purpose "C"- or "D"-cell battery and measure its open circuit voltage with an accurate digital voltmeter. I've found most 1.5-volt cells to check out at about 1.54 volts. Connect a 15,400-ohm resistor (actually a 15k one will be close enough, with an induced error of less than 3%) in series with either a "C" or "D" cell, and adjust R11 for a full-scale reading of 100 microamps. Use a 150k resistor for the 10-microamp range, and a 1.5-megohm resistor for the 1-microamp range.

LOW-VOLTAGE VOLTMETER

Our next entry, see Fig. 2, turns the current amplifier circuit in Fig. 1 into a sensitive low-voltage voltmeter that provides full-scale readings of 0–1 volt, 0–100 mV, and 0–10 mV. With S2 set to position 1, op-amp U1 provides a DC-voltage gain of about 100 (voltage gain = R6/R3); in position 2 the gain is ×10; and in position 3 the gain is ×1.

The voltmeter's operation is very similar to that of the previous circuit. The input

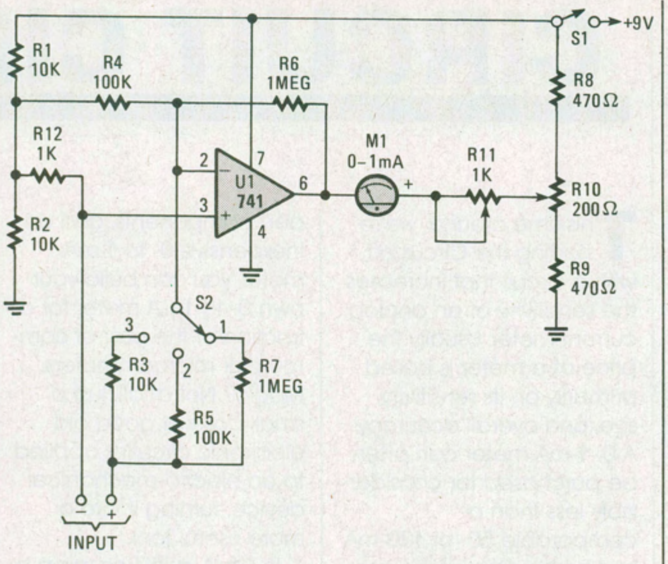

Fig. 2. A slight modification to the microammeter circuit of Fig. 1 transforms it into a low-voltage voltmeter.

PARTS LIST FOR THE LOW-VOLTAGE VOLTMETER

RESISTORS

(All fixed resistors are ¼-watt, 5% units.)
R1–R3—10,000-ohm
R4, R5—100,000-ohm
R6, R7—1-megohm
R8, R9—470-ohm
R10—200-ohm potentiometer
R11—1000-ohm potentiometer

ADDITIONAL PARTS AND MATERIALS

U1—741 op-amp, integrated circuit
M1—0–1-mA meter
S1—SPST switch
S2—SP3T switch
Perfboard materials, enclosure, IC socket, test terminals, 9-volt battery, battery holder and connector, wire, solder, hardware, etc.

voltage is fed to the inverting input of U1 at pin 2 through one of three multiplier resistors (R3–R5), which are selected by S2. The output of U1 is monitored on the same 0–1 mA meter that's used in the previous circuit.

METER-CALIBRATION CIRCUIT

Before the circuit can be expected to function properly, it must be calibrated. That is easily done with the handy little voltage calibrator circuit shown in Fig. 3. In that circuit, R4 the 3-ohm unit, was made by paralleling one 27-ohm and three 10-ohm resistors. A low-cost D-cell battery, in conjunction with a resistor divider network, makes up a simple calibrator circuit that supplies output voltages of 1 volt, 100 mV, and 10 mV. You'll need an accurate DC voltmeter in setting R1 for a 1-volt output at switch position 1. If an accurate voltmeter isn't available, use an ohmmeter and set R1 to 150 ohms. That will get you close enough for calibrating our voltmeter circuit.

Set the voltmeter's input switch, S2, to position 1, and connect the input to the calibrator. Zero the meter with R10, and with the calibrator switch in the 1-volt position, press S1, and adjust R11 for a full-scale meter reading. Each voltmeter range can be checked and re-calibrated in the same manner.

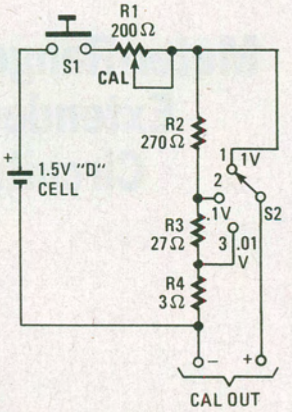

Fig. 3. As with all circuits used to monitor some quantity, the voltmeter circuit of Fig. 2 must be calibrated against a standard. This circuit is ideally suited to that task.

LOW-RANGE OHMMETER

Our next circuit, see Fig. 4, turns the meter amplifier into a linear low-range ohmmeter with ranges of 0–1, 0–10, and 0–100 ohms. Transistor Q1 and its associated components make up a constant-current circuit that supplies a 1-mA current to the test terminals. Two 9-volt batteries provide power for the circuit, allowing the input and output circuitry to be referenced to ground. That power arrangement helps to simplify the overall circuit. Two 1N914 silicon diodes, D1 and D2, offer some overload protection to the meter. Potentiometer R9 can be used to zero the meter, while R10 is used to set the meter for a full-scale reading.

If we connect a 1-ohm resistor to the test terminals (R_X), the constant-current circuit will pass 1 mA of

PARTS LIST FOR THE METER CALIBRATION CIRCUIT

RESISTORS

(All fixed resistors are ¼-watt, 5% units.)
R1—200-ohm potentiometer
R2—270-ohm
R3—27-ohm
R4—3-ohm, see text

ADDITIONAL PARTS AND MATERIALS

B1—1.5-volt D-cell battery
S1—Normally-open pushbutton switch
S2—SP3T switch
Perfboard materials, enclosure, test terminals, wire, solder, hardware, etc.

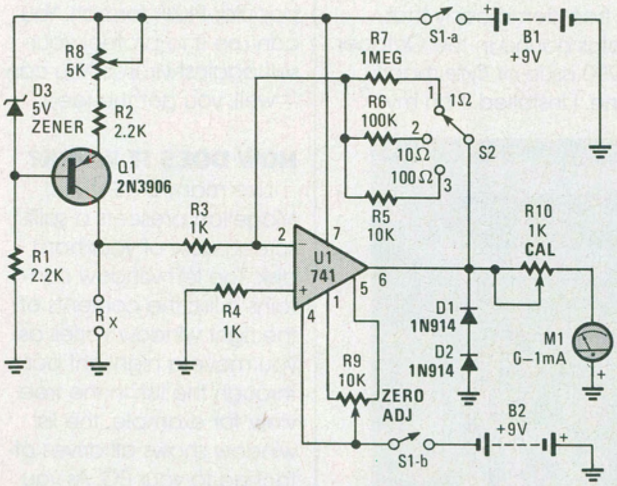

Fig. 4. In this circuit, a general-purpose PNP transistor (Q1) and a 741 op-amp (U1) combine to provide a low-resistance range for your ohmmeter.

PARTS LIST FOR THE LOW-RANGE OHMMETER

SEMICONDUCTORS

U1—741 op-amp, integrated circuit
Q1—2N3906 general-purpose silicon PNP transistor
D1, D2—1N914 general-purpose small-signal silicon diode
D3—5-volt Zener diode

RESISTORS

(All fixed resistors are ¼-watt, 5% units.)
R1, R2—2200-ohm
R3, R4—1000-ohm
R5—10,000-ohm
R6—100,000-ohm
R7—1-megohm
R8—5,000-ohm potentiometer
R9—10,000-ohm potentiometer
R10—1000-ohm potentiometer

ADDITIONAL PARTS AND MATERIALS

B1, B2—9-volt transistor-radio battery
M1—1-mA meter
S1—DPST switch
S2—SP3T switch
Perfboard materials, enclosure, AC molded power plug with line cord, battery(s), battery holder and connector, wire, solder, hardware, etc.

current through the resistor, developing a 1-mV drop across the resistor. The op-amp's input is connected in parallel with the test resistor and senses the minute DC voltage. The amplifier's gain in the 0–1-ohm range is 1k. The 1-mV signal is amplified 1000 times, producing a negative 1-volt output at pin 6 of U1.

The 1-volt signal is fed to the 0–1-mA meter through R10 to indicate a full-scale reading, which converts to the value of the test resistor, or 1 ohm.

Since the ohm scale is linear, all meter markings will read in ohms. For example, 0.5 mA = 0.5 ohms, and 0.25 mA = 0.25 ohms, etc. Of course, in the 0–100-ohm range, the values would be 100 times greater; *i.e.*, 0.5 mA would equal a 50-ohm reading.

In all three ranges, the current flow through the test resistor remains at 1 mA, and only the amp's gain is changed. If you would like to build a low-ohm meter for your test bench, the cost, if you already have a 1-mA meter and a full junkbox, should be minimal. Be sure to use an IC socket for the 741 op-amp.

Before a reading can be taken, the circuit must be calibrated. To do that, set R8 to its maximum resistance and S2 to 100 ohms (position 3). Connect an ammeter in series with the test terminals (R_X) and apply power. Adjust R8 for a 1-mA reading on the ammeter connected across R_X. Remove the ammeter from R_X, short the test terminals together, and zero M1 by adjusting R9. Connect a 100-ohm, 1% resistor to R_X and adjust R10 for a full-scale reading. The other two ranges can be calibrated in the same manner with a 10-ohm and a 1-ohm resistor. ■